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Genetic prospecting and biodiversity development agreements

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Abstract

Biodiversity loss continues, in part, because local benefits from wildland preservation are limited. Biodiversity development agreements (BDAs) intend, through bioprospecting efforts, to distribute benefits of biodiversity to those who bear preservation costs. Analysis of two case studies suggests that monetary returns from bioprospecting could be substantial, though realization of returns is uncertain and likely to take time. Considerable non-monetary benefits from BDAs have included training and increased infrastructure and institutional capacity. BDAs probably will not finance desired land preservation, nor is it certain they can influence land use. Nonetheless, carefully structured BDAs can be useful components of biodiversity conservation programs. Published by Elsevier Science Ltd.

Keywords: Biodiversity; Conservation policy; Genetic resource conservation; Land use

Introduction

Conserved biodiversity has many values: direct resources for agriculture and medicine, numerous environmental services, and option, bequest and existence values. Despite these values, biodiversity loss arises because its benefits typically are diffuse and longer term, while the opportunity costs of preserving land (and thus, biodiversity) are borne immediately by local communities. Further complications arise because naturally-occurring biodiversity may not be protected by any intellectual property rights, making it difficult to extract rents for resources valued by society as whole, from the producers of final products. Fixing this market failure requires mechanisms to share some of the diffuse, long-run returns with those who bear the immediate and local costs.

Biodiversity development agreements (BDAs) are one possible mechanism to correct these market failures. BDAs are agreements between the holders of biodiversity (usually a developing country) and users of biodiversity (usually a private firm) to share resources and the gains from new product development. BDAs seek to link the interests of diversity holders and users through coordination of biodiversity prospecting efforts.

Generally, there are two objectives of biodiversity prospecting efforts. The first is to discover and use certain genetic resources. There are many species that have never been sampled or assessed, some of which potentially could benefit agriculture or industry (particularly pharmaceuticals). The second objective is to give local people a return for the conservation of biodiversity. These agreements are intended to help countries and local communities capture a greater share of the external benefits of resource conservation. By tying future benefits to maintenance of the resource base, BDAs may increase a country's incentives for preservation. Possible benefits from BDAs also include up-front payments, training, and technology transfer. These benefits give countries more scientific and financial resources, thus increasing their capacity to carry out conservation activities. Many agreements encompass both objectives, and specifically seek to foster resource conservation in situ.[1]

While these agreements are often between a private company and the government of the source country, their success is dependent on the transmission of

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[1] Because the primary source of biodiversity loss is the destruction of habitat (McNeely, 1995), biodiversity conservation generally means the preservation of wildland. Thus, in situ conservation is often a primary goal of BDAs, at least from the public participants' perspective.

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sufficient benefits to local communities to offset the opportunity costs of other land uses. Thus, incentives for resource conservation by local people will be affected not only by the amount of returns from a BDA, but also by the distribution of these returns.

BDAs have been touted as a potentially important means to increase the marginal benefits of biodiversity preservation (Rausser and Small, 2000; Simpson and Sedjo, 1992; Eisner, 1989–1990; Blum, 1993; Sandler, 1993; Reid et al., 1993; Roberts, 1992). However, BDAs have been questioned, with some suggesting that their benefits are likely to be negligible (Simpson et al., 1996; Southgate, 1998), or their impact small (Terborgh, 1999). Others have noted negative reactions to bioprospecting activities from the very groups purported to benefit from the agreements (Kaufman-Zeh, 1999), or the lack of distributional equity for benefits (Barrett and Lybbert, 2000). This paper assesses the role of BDAs in creating incentives to conserve biodiversity, in the context of certain market failures. After providing an overview of the economic research, we will present two case studies of biodiversity development efforts, one in a developed country, and one in a developing country. Analysis of these two case studies offers an empirical review of the incentives BDAs can provide for biodiversity conservation, including benefits not typically measured in theoretical analyses. The two case studies also give insight into what factors influence the effectiveness these agreements and how BDAs can be structured to maximize benefits. The first case study reviews the development of the anticancer drug taxol, through a US natural products program. The second case study assesses the BDA between Merck & Company, the pharmaceutical multinational, the Instituto Nacional de Bioversidad (INBio), a Costa Rican non-profit private organization, and the government of Costa Rica. The paper concludes with a discussion of the potential for this and other agreements to provide incentives for biodiversity conservation.

The economics of in situ conservation

Why are incentives for biodiversity conservation needed? Swanson (1994b) notes that biological resources must be productive in order to be retained. Within human dominated systems, he finds that biological resources face two threats. The first arises from being highly valued, which can result in unsustainable harvesting. The second arises because a resource has relatively less value than competing resources.[2] In this case, a resource or set of resources may be converted to another use.

Observers sometimes point to "proximate" and "underlying" causes to explain biodiversity loss.[3] According to the UN's Environment Programme, primary proximate causes of biodiversity loss are harvesting, land conversion, and pollution activities. The underlying cause is found in the differences between the private values and social values associated with biodiversity (Perrings et al., 1995). The private returns to the holders of biodiversity are lower than the social returns (Hanemann, 1988; Janssen, 1999). Private returns are important because many decisions that affect conservation of biodiversity, such as land clearing or crop variety selection, are made at the individual or local level. By contrast, many of the benefits of biodiversity conservation accrue at the national or global level (see Janssen (1999), for discussion of the role of property-rights regimes in the appropriation of benefits). Also, people often prefer to consume resources in the present, rather than in the future. Together, these factors generate private or individual decisions that differ from those that are socially or globally optimal.

Markets do not exist for most of the environmental services provided by biological diversity. Therefore, in the case of land conversion, keeping land in its natural state may reduce or eliminate the land's earning capacity for its holders. Private returns to agricultural use form one opportunity cost of wild land preservation; in some cases, this cost may be quite high for the private land user (Barrett and Lybbert, 2000; Forster, 1992; Binswanger, 1991).[4]

Genetic resources of interest to prospectors potentially face both of the threats described by Swanson. Because genetic resources of interest to prospectors may also be used by local population as medicinals, they could, in theory, be over-harvested. However, to date, this has not been a significant problem. The primary reason biodiversity is being lost lies with the second threat, the resource conversion (Kaimowitz and Angelsen, 1998). This is illustrated in Fig. 1, which depicts the local and global incentives for in situ genetic resource conservation (based on Larson, 1994; see also Janssen, 1999). The horizontal axis represents the stock of land available to the local community, initially all in a natural (and diversity-rich) state. Reading from right to left as more land is converted (e.g. to agricultural production), MB_{con} maps out the benefits to local inhabitants of converting an additional acre. (As such, MB_{con} also represents the opportunity cost to local residents of

[2] According to Sandler, loss can arise from base resource (e.g. land) re-allocation and or management service re-allocation. Both stem from the re-allocation of resources to more competitive assets.

[3] There are many different assessments of what constitutes a proximate cause and what is, in fact, an underlying cause. The UNEP description was chosen in hopes that it would present a consensus view. See Kaimowitz and Angelsen (1998), and Day-Rubenstein et al. (2000) for literature reviews.

[4] Pollution activities also arise from private values of external resources that are lower than public values (as well as from failures to fully internalize production costs).

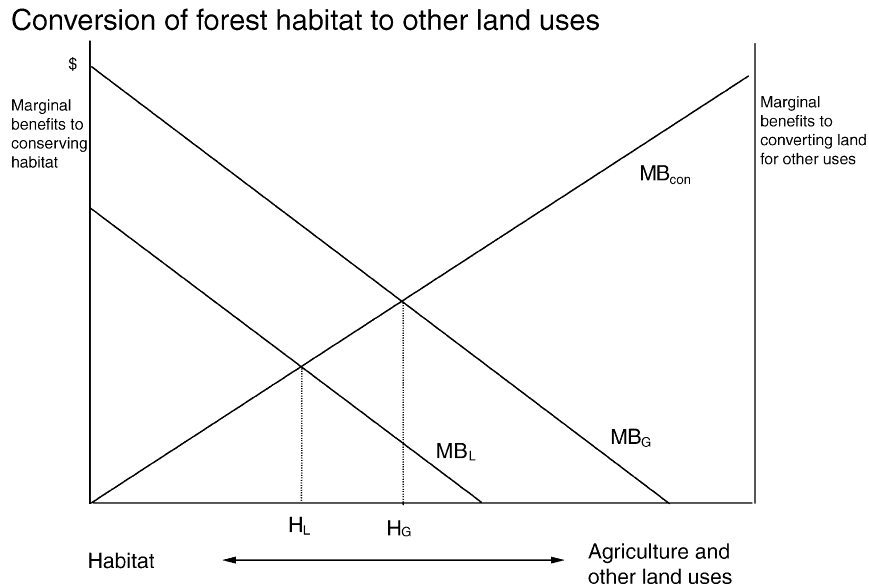

Fig. 1. Conversion of forest habitat to other land uses.

preserving an additional acre.) Reading from left to right, MB_L shows the benefits to local residents (e.g. in fuel, forage, traditional medicines, or other goods of local value) of keeping an additional acre of land in its natural state. Given these costs and benefits, the local inhabitants would choose to preserve land up to the point H_L. The global benefits of preserving an additional acre, MB_G, are higher, reflecting the public goods nature of diversity benefits. Global benefits from preservation would include (in addition to the local benefits) the expected direct use value of genetic resources (e.g., as crop germplasm or pharmaceuticals) as well as global environmental services performed by these resources. Global benefits would also incorporate some measure of option value and existence value (Barbier et al., 1995). For the world as a whole, the optimal preservation level would be H_G, higher than the local optimum.

Because local inhabitants do not capture many global benefits of biodiversity preservation, the factors affecting the marginal benefits to conversion (MB_{con}) play a role in determining the extent of land conversion. However, national and international policies may be able to shift the location of curve MB_L and increase the local incentives for in situ preservation of biologically diverse resources. The second stated objective of the bioprospecting instrument is to increase the local returns to biodiversity conservation. The desire by policymakers to increase local returns is seen in the UN's Convention on Biological Diversity. By granting individual countries sovereign rights over their genetic resources, it was hoped that countries would have greater incentives to preserve these resources. (While bioprospecting existed prior to the Convention coming into force, the Convention has raised the profile of such agreements.)

The effort to increase returns to the holders of genetic resources is complicated by market failures or absences of markets for genetic resources (Brown, 1987; Sedjo, 1992; Simpson and Sedjo, 1992; Sandler, 1993). Certain genetic materials are easy to transport and replicate once collected. Therefore, fully capturing returns require that a holder have both physical and intellectual rights to a genetic resource. Some resources are costly if not impossible to reproduce, while others can be rapidly reproduced at low costs. In these latter cases, countries may have difficulty capturing even a fraction of the value that flows from their genetic resources. Even with more complex resources, having sufficient knowledge about a genetic resource can, in some cases, substitute for the resource itself.[5] Consequently, intellectual property associated with a resource can be as important as the resource itself.

In theory, strengthening intellectual property rights for genetic resources should shift the MB_L curve to the right. If benefits are more easily appropriated, they should increase the incentives for conservation. However, practically speaking, the role of intellectual property is more complicated. While the Convention addresses intellectual property rights, a global, systematic mechanism for protecting intellectual property is still lacking. Thus, rights to intellectual property are generally determined by the supplier and recipient of a genetic resource, if at all. However, developing countries may find that the costs of obtaining the legal and institutional resources needed to establish intellectual property outweighs its benefits (Kaufmann-Zeh, 1999; Miller, 1999). Moreover, intellectual property law in

[5]The advent of biotechnology has facilitated the replication of genetic resources.

some developed countries, notably the US, is designed to protect biological inventions, not biological resources as found in nature. To wit, Janssen (1999) notes that regimes distinguish between property rights for genetic resources (material goods) and property rights for the information contained in genetic resources (immaterial goods which result from the research process). Another complication arises because, as countries seek to incorporate the Convention's provisions into their intellectual property laws, World Trade Organization (WTO) members must sign and implement Trade Related Aspects of Intellectual Property Rights (TRIPs). WTO members face sanctions unless their TRIPs requirements are met. However, some view the TRIPs provisions as incompatible with the Convention (Macilwain, 1998). Janssen (1999) states that, if material genetic resources are in open access property systems, TRIPs provisions, which are focused on inventions, may have adverse affects on global biodiversity. Finally, intellectual property regimes do not guarantee that benefits are channeled to those who hold and/or make decisions affecting the use of land with genetic resources (Swanson, 1995). This is not to say that they could not be structured to do so (Swanson, 1994a), merely that many such regimes do not benefit the people using land resources at the local level. Consequently, the effects of the Convention remain unclear, and the role of intellectual property rights varies among nations.

Biodiversity prospecting

Institutional arrangements

Biodiversity prospecting generally begins with the collection of genetic material. A source country agrees to supply, or allows access to, certain genetic resources. Collectors gather and taxonomically identify a supply of samples for screening. Those samples are evaluated for their potential industrial benefits. Companies give source countries funds, either in advance, and/or from royalties on any compounds commercialized from the collected samples (Laird, 1993). Most BDAs have focused on the supply of biological samples for pharmaceutical development.

In the past, interested prospectors simply collected resources from source countries. Some times, though not always, a small sample fee was paid. One often cited example of this system was Madagascar's rosy periwinkle. The rosy periwinkle was the source of the anticancer drugs vincristine and vinblastine, sales of which have exceeded $100 million. Madagascar never received any payments for the use of this native resource (Rubin and Fish, 1994; Blum, 1993). BDAs, ideally, would prevent a situation, such as that of Madagascar's, from recurring.

These agreements can and have varied greatly in their composition. The source country may simply provide access to natural resources. Or, the source country can provide complete prospecting services, and screen and evaluate the samples. The division of labor found in most BDAs falls somewhere between these two examples.

The makeup of the agreement is also affected by the search strategy. For instance, drug prospecting entails collecting samples that are screened for activity vis-a-vis a certain disease (e.g. cancer, AIDS). Prospecting can focus on random collections of plants or other living things. Drug companies often prefer random collection, because it yields more diverse samples (Rouhi, 1997). Drug companies generally screen large numbers of compounds very quickly. The chances that any single sample will test positive are small, but many samples are tested. Prospecting can also be "targeted," and sample collectors may use ethnobotanical or ethnomedical information. Generally, targeted samples are collected and screened on a slower, smaller scale, and more time may be devoted to evaluating the activity of a given sample. In this type of prospecting, the source country often supplies traditional knowledge (Rubin and Fish, 1994).

The methods of compensating source countries also vary, and can be complex. In the simplest model, the source country is paid a fee for samples.[6] Often, BDAs provide the source country with royalties from the sale of a successful product, should one be developed. Here, the source country faces the possibility that such a compound may not be found, and thus, no royalty payments may be received. Royalty provisions often have an inverse relationship with up-front payments (Rubin and Fish, 1994). Rosenthal (1996) states that in order for BDAs to achieve their objectives, there must be near-term benefits to source countries, as well as long-term returns. Advanced payments are increasingly important to these countries that, as a group, have limited financial means. A more complex model involves the use of ethnobotanical or ethnomedical data that may raise complicated intellectual property rights issues because the suppliers of traditional information may need to be compensated (Rouhi, 1997). A royalty scheme may become further complicated if indigenous knowledge was used to select the sample and the sale of the product takes place some time in the future.[7] Other forms of compensation may include technology transfer,

[6] However, some BDAs limit the time a prospecting company has use of a sample. When source countries limit prospector's screening right, they may provide a mechanism to extend this right should a sample prove interesting (Rubin and Fish, 1994).

[7] Rubin and Fish (1994) maintain that local people should be compensated regardless of their participation in the search process, because their land and resource use decisions have conserved the biological resource.

training, job opportunities, and the right of first refusal as supplier of the resource (Rubin and Fish, 1994).

A number of such agreements are already in place. The US National Institute of Health has a set of material transfer agreements governing control and distribution of genetic resources and cooperative research agreements between developing countries and private firms for product development (Day and Frisvold, 1993). The US Agency for International Development has also implemented a program to encourage joint biodiversity research and development between developing countries and private industry (Cohen, 1992). Such agreements often have explicit clauses giving cooperating companies first rights to file for patents or other intellectual property rights.

Values of natural pharmaceuticals

Typically, economic valuations of biodiversity prospecting have focused on private, external interests in pharmaceuticals. Genetic resources are important sources of new pharmaceutical products (Reid, 1995). Natural products (i.e., products derived from naturally occurring living things) have long been a source of medicinal substances. Twenty-five percent of the prescription drugs sold in the US contain active ingredients derived from plants (Reid, 1995). Even more drugs originally came from plant or animal products, or use natural products in some part of the formula. Worldwide, the World Health Organization estimates that 80% of the world's population relies on plant-based medications (Lancet, 1994).

Natural products are a desirable source of pharmaceuticals for two reasons. First, living creatures must protect themselves. Consequently, they produce substances that are toxic to undesirable intrusions or growths (Blum, 1993). Secondly, natural substances are often much more diverse than synthetic substances. It was possible that nature would produce an antitumor agent that would never occur to a researcher (Rouhi, 1997; Macilwain, 1998).

Interest has grown in natural products as a source of new drugs. Pharmaceutical companies did virtually no higher-plant research in the early 1980s. Now, over half the top 250 companies have such a program (Lancet, 1994).[8] This focus on natural products as active pharmaceutical ingredients has given some holders of biodiversity hopes for profiting from the development of bio-based drugs. New bio-based drugs on the market include topotecan and irinotecan, which are analogs of camptothecin found in India and China used to treat cancer (Hunter, 1997; Wall and Wani, 1995) Artemisinan, derived from *Artemisia annua*, is used to treat malaria in Southeast Asia, Africa, and Switzerland (where it is a component in the drug Riamet). In North America, Artemisinan is being evaluated as a treatment for drug-resistant malaria in humans, and as an antiacoccidial for poultry (Allen et al., 1997). However, an interest in natural products by pharmaceutical companies does not necessarily lead to bioprospecting activities. Miller (1999) notes that interest in bioprospecting has passed its "initial spike of interest," though today interest is at a consistent level. Macilwain (1998) suggests that prospecting has not lived up to expectations, at least those of resource-rich source countries. However, he also states that activity has been fairly steady over the last ten years and industry interest is likely to accelerate in the future.

Estimates of the values of undiscovered drugs are generally high. Mendelsohn and Balick (1997, see also 1995), assessed the value of undiscovered pharmaceuticals in tropical forests and found that the net value to society of these drugs was about \$109 billion. Using ecological expectations of plant extinctions for the year 2000, Farnsworth and Soejarto (1985) estimated the total value of potentially extinct plant species to be more than \$3 billion in the United States alone (1985). The value of species in diversity-rich areas was thought to be much higher.

Certain studies have sought to quantify the value of biodiversity for pharmaceutical products, in terms of land conserved.[9] Generally, the probability of a successful find (or a "hit") and the expected benefits from drug sales are apportioned over (or weighed against) the land conserved.[10] Barbier and Aylward (1996) analyzed royalty returns from pharmaceutical prospecting, based on data from Costa Rica. Using a biodiversity investment choice model, the authors compared the costs of producing samples (i.e., collecting, identifying and characterizing samples of genetic material) and the opportunity costs of preserved land with expected royalties. Results suggested that source countries could be adequately compensated for investments in collecting and characterizing their samples, but

[8] Though Terborgh (1999) notes that, overall, industry reliance on synthetic products is increasing.

[9] Area preserved is a useful measure of biodiversity preservation, because conversion of wildlands is the primary threat to biodiversity. However, we should note that there is uncertainty about the relationship between land preserved, and species protected (Lugo, 1988). Species vary in regards to the area of habitat which they need, and different types of land have different species–area relationships (Pimm and Raven, 2000). Thus, the benefits in terms of species (or other measure of biodiversity) preserved per unit of land set aside are unclear. Likewise, questions remain about how much land must be preserved in order to protect a given set of biologically diverse resources.

[10] Cragg et al. (1998) note that the US National Cancer Institute screened plants for anticancer activity from 1960 to 1982. The success rate was about one in 4000. This empirical example of a success rate is higher than those generally suggested in the literature and used in valuation studies.

are unlikely to cover the full costs of biodiversity preservation. The study by Mendelsohn and Balick (1997, based on 1995) also expressed their value of undiscovered pharmaceuticals in terms of land area, about $3 per hectare of tropical forest. The authors note that the social value of these undiscovered pharmaceuticals is much higher than the value to a drug company. Using different methodology, the same authors, in Balick and Mendelsohn (1992), valued traditional medicines for Belize. Forests used for traditional medicine production were estimated to be worth $726–3327 per hectare, present value. Such values compare favorably with alternative land uses, such as intensive agriculture. In this case, the authors limited their valuation to traditional medicines.

Several studies have focused on assessing the marginal value of genetic resources. The authors assess returns to the owners of genetic resources, as opposed to net social benefits of drug discovery. Simpson et al. (1996) valued marginal species (i.e. the value of preserving an additional species) for 18 biodiversity "hot spots". Their model was a one disease, one drug model (i.e. prospectors are looking for only one disease, and once a successful "hit" is found, no other drug will be needed). They find that the value of a marginal species is low. The maximum willingness to pay to preserve a hectare of land in western Ecuador was estimated at $20.65 per hectare (the highest value found). Consequently, the authors argue that pharmaceutical prospecting is not a viable method for financing biodiversity conservation. Rausser and Small (2000) also valued genetic resources in a bioprospecting context. Like Simpson et al., they used a one disease, one drug model. However, citing industry practices, they assumed a targeted search model. The authors found that genetic resources had much higher marginal values in a targeted search structure. Publicly available information allows prospectors to optimize their searches. Promising leads command "information rents" because they may (1) increase the probability that a successful hit will be found and (2) reduce the number of searches needed to find a hit. Rausser and Small found that, using the strategy that optimizes testing of resources, the highest incremental value is $9177 per hectare found in Western Ecuador.

The broad range of values found in these studies highlights the fact that economic valuation of biodiversity prospecting is sensitive to assumptions and methodologies. A primary limitation to the marginal value approach has been the one-disease/one drug assumption. In reality, prospectors do not really expect to find a "cure" for many diseases. They are looking for activity against certain compounds. Generally, the search will not end when a compound with activity is found, or even when the final pharmaceutical product is marketed.

Other qualifications to economic studies arise from the recent advances in biotechnology that have allowed pharmaceutical companies to increase the speed with which they screen samples for activity against diseases, reducing screening costs.[11] Thus, actual screening rates are often higher than most of those used in these studies. Likewise, the value of a unique drug may be much higher than the amount used to calculate royalties, because some researchers used average drug value. On the other hand, the increasing populations found in many developing countries are expected to raise opportunity costs for land preservation. Therefore, the net effect of these changes is ambiguous. Finally, assumptions about the time lag between collection and the marketing of a drug may not accurately reflect their significance for investors in bioprospecting, public or private, for whom time lags can be a key issue.

Other values and issues

Prospecting valuation often has been limited by the focus on pharmaceuticals. Other important potential uses for biologically diverse resources exist (Special Panel, 1997). When prospecting is expanded to resources of possible interest to agricultural production, the probability of a marketable find increases. One such agreement is between the National Botanical Institute (NBI) of South Africa and the US-based Ball Horticultural Company, which addresses bioprospecting for the horticultural and floriculture sector (Henne and Fakir, 1999).[12] Another way in which genetic resource samples could be used to further agricultural production is through the development of agrochemicals, such as pesticides. Demand for biologically-based agrochemicals has increased. As society seeks to minimize environmental externalities, biopesticides are of special interest because often they are more environmentally benign than synthetic pesticides. Areas rich in biodiversity are promising sources of natural agrochemicals for the same reasons that they are promising sources of pharmaceuticals, because species in a diverse and competitive environment must develop self-protective

[11] Rausser and Small (2000) maintain that information rents associated with high-quality leads actually decline when search costs fall, because the lead's "competitive advantage" is less.

[12] Beyond brief mention of the Ball-South Africa agreement, we have not discussed the use of BDAs for resources used in the breeding of new crop varieties and livestock breeds for two reasons. First, due to the US policy of free and open exchange of unimproved agricultural genetic resources, a BDA for crop (or livestock) genetic resources would not be a within the scope of US conservation policy (even for farmer-developed varieties). Second, while the returns to genetic improvements for agricultural purposes are significant, there is limited economic evaluation of "raw" genetic resources independent of breeding efforts. Simpson and Sedjo (1998) suggest that returns to the biological resources used for crop improvement, by themselves, are limited.

Table 1
Some values of wildlands and BDA assessments

Potentially, many direct values of preserved biodiversity could be addressed by BDAs. However, assessments have focused on a narrow group of these values. Of course, preserved biodiversity holds many other values, but indirect use and non-use values are unlikely to generate returns from BDAs. (See Swanson (1995), for a list of values from a dynamic and static perspective.)

Direct use	
X	Food and fibers, building and industrial materials
X	Fuel
X	**Medicines for local people**[a]
X	**Pharmaceuticals**[a]
X	Agricultural inputs
	Genes for plant and animal breeding
	Pesticides useful for agriculture
	Microorganisms useful for agricultural production
X	Recreation (e.g., visits to wilderness sites, bird watching)
Indirect use values	
X	Habitat for plants, animals and microorganisms
X	Habitat for migratory species, including pollinators used by agriculture
X	Watershed protection
X	Soil protection
X	Storage and recycling of human-produced wastes
X	Carbon storage
X	Climate regulation
Option values	
X	The option for any direct or indirect use in the future (e.g., future agricultural, medical, industrial and climate control needs)
Quasi-option values	
X	The value of information held in conserved resources
Bequest values	
X	The value placed by some people on leaving resources for future generations.
Existence values	
X	The value placed by some people on the existence of a biodiversity they never expect to see or use (e.g., the value of knowledge that Siberian tigers survive)

[a] Values addressed by the BDA assessments described in this paper.

mechanisms. The pesticide/fungicide neem is one example of a natural compound being used as agricultural chemical. However, it was not discovered within the confines of a bioprospecting agreement. If such a compound were discovered as a result of a BDA, the source country could benefit financially.

In addition to serving as inputs into the agricultural production process, unique genetic resources may have promise as food-related products and industrial products. The food industry is interested in natural flavorings and preservatives. Another potential market lies within the emerging area of food called "functional food" or "nutraceuticals." These foods offer superior nutritional or health-enhancing properties, and may make use of natural products found in genetically-rich source countries (Macilwain, 1998). Miller (1999) notes that a successful herbal tonic (using *Trichopus zeylanicus*) has led to royalties for the Tropical Botanical Garden and Research Institute in Trivandrum, India, as well as local residents.[13] Other prospecting-related uses of biodiversity include industrial uses such as natural products as lubricants, for bioremediation, and in cosmetics.[14]

Besides offering additional sources of financial returns, the development of agricultural and industrial uses of natural products entails smaller (if any) regulatory burdens compared with drug approvals. Moreover, they often do not take as long to develop as pharmaceuticals (Special Panel, 1997).

Natural products may continue to be of interest, even if it is just for their parts, rather than their whole. Some see genetic prospecting for genes, to be used in combinatorial chemistry, as a promising avenue for bioprospecting (Macilwain, 1998; Firn and Jones, 1998).

Other benefits typically not accounted for in valuation estimates are increases to the source country's scientific and technical capacity. First, some, though not all, BDAs are structured so that the source country receives equipment, training, and/or employment opportunities (Barbier and Aylward, 1996). Second, because bioprospecting is a labor-intensive activity (Miller, 1999), private or public institutions within a source country can provide services such as collection, preparation and processing of samples. Such value-added prospecting activities by source countries may increase returns, if payments for services outweigh the costs of providing them.[15] Third, another benefit arises from the collection of biologically-based data. Such information may have commercial value, regardless of whether genetic resources are used in a marketed product (Nature Biotechnology, 1998).

Finally, BDA evaluation to date focuses on the returns to prospecting activities. However, the conservation of biodiversity yields a broad range of benefits (see Table 1). Thus, such evaluations fall short of reflecting the full social value of biodiversity preservation.

[13] The development and marketing of *Trichopus zeylanicus* has not been without controversies, mainly stemming from problems assigning and enforcing rights to both intellectual and physical property. However, payments to the Kanis tribe did begin in 1999.

[14] Jojoba is one example of a previously little known genetic resource that has been economically important for cosmetic manufacturers.

[15] The equipment and training needed for value-added bioprospecting activities can require a substantial investment if a country's human and institutional capital is not sufficiently developed. As stated in the first point, such resources are sometimes part of the source country's benefits.

Evaluating biodiversity development agreements: two case studies

BDAs could, in theory, provide greater marginal benefits and financial resources for preservation (as suggested by Fig. 1). However, BDAs are relatively new instruments. Because prospecting generally involves a time lag between initial collection and development of a final product, assessing BDAs has been difficult. Consequently, we examined the development of a natural product pharmaceutical in the US.

The taxol case study

The development of the anticancer drug taxol involved many of the same issues found in genetic prospecting scenarios. Naturally, there are limitations to applying the taxol experience to the arena of BDAs. Taxol's development is one individual case that took place primarily within one developed country, while BDAs can have many variations. Nonetheless, some interesting lessons from the taxol experience illustrate the benefits that can be associated with prospecting for natural products, as well as some limitations to the impacts of successful drug development on land use decisions.

Background

In a desire to find cures for cancer, the US National Cancer Institute (NCI) screened more than 130,000 naturally occurring substances for antitumor activity between 1960 and 1981.[16] USDA was responsible for collecting plants, while NCI focused on screening samples for anticancer properties.

The bark from the Pacific yew tree, *Taxus brevifolia*, was first collected by USDA for initial screening in 1962. Early researchers were interested in taxol's antitumor activity (Wall and Wani, 1995). In 1971, the taxol molecule was isolated and information about its structure published.[17] Therefore, the isolated taxol molecule was in the public domain and could not be patented. Later studies suggested that taxol had high activity against melanoma and a unique mode of action.

Based on clinical trials during the 1980s, NCI believed that taxol could be an effective new cancer treatment and wanted rapid diffusion of the drug. However, diverse levels of expertise were needed to overcome a number of daunting problems before taxol could be produced on a commercial scale.

Although taxol was derived from tree bark, this resource stock was not readily renewable. The production and marketability of natural products may be limited if resources are scare, or slow growing. For a promising drug, such as taxol, the demand could easily outstrip the existing stock. Moreover, because the pacific yew was often found in publicly-held old growth forests, harvesting strategy would be subject to regulations regarding operation on public lands and the Endangered Species Act.

Appropriability was also problematic, because taxol could not be patented. Therefore, NCI needed to provide sufficient incentives for private pharmaceutical firms to make the considerable investments necessary to gain Food and Drug Administration (FDA) approval and begin large-scale production of taxol without the benefit of patent protection.

In order to overcome these problems, NCI entered a cooperative research and development agreement (CRADA) with the pharmaceutical company Bristol-Myers Squibb to develop taxol commercially.[18] NCI would work exclusively with Bristol to develop and market taxol. In exchange, Bristol would supply NCI with taxol for clinical trials, collect clinical trial data and related research, and fund research to develop taxol from sources other than the bark of the Pacific yew.[19] The CRADA was constructed so that NCI had the right to terminate the agreement if the taxol had not been commercialized quickly.[20]

In cases such as taxol's, the lack of intellectual property rights is often cited as a possible limitation to genetic resource development. Through the CRADA, NCI could offer a degree of private appropriability. The CRADA, and subsequent research agreements, allowed Bristol to appropriate some benefits of basic, public scientific knowledge. Exclusive information and data gave Bristol a substantial head start in the development of taxol and taxol-like drugs. Such a lead time can often substitute for intellectual property rights, and allow taxol formulations produced by Bristol to be widely adopted before similar drugs. Taxol has been deemed a success, with one of the fastest approvals on record (albeit about 30 years after its initial collection). Why did the NCI-Bristol CRADA succeed? Success was due, in large part, to a carefully constructed research

[16] Aylward (1995), provides a detailed review of NCI's program.

[17] While researchers urged the further development of taxol early in the research process, NCI responded that the compound was too limited, the source trees were also limited and that extraction and isolation were difficult (Wall and Wani, 1995).

[18] Cooperative Research and Development Agreements are the legal mechanisms used by the US government to encourage joint research ventures between private industry and public research institutions, established under the Federal Technology Transfer Act of 1986.

[19] Several other agreements gave Bristol exclusive right to harvest yew bark on lands held by Federal agencies for five years.

[20] Had Bristol "failed to exercise best efforts in the commercialization of taxol" NCI could have terminated the CRADA and worked with another company. NCI also was not precluded from commercializing taxine drugs with other companies, and entered another CRADA to explore taxine drugs.

agreement that provided sufficient commercial incentive, accountability for Bristol, and environmental protections.[21] Taxol development can provide insight for BDAs in developing countries. Six lessons learned from the taxol experience are summarized below.

Lesson 1. The impacts of prospecting and harvesting on in situ resources are unclear, and other means of protection may be necessary. Of the two threats described by Swanson (1994b), the pacific yew first faced potential loss from habitat conversion, because these yews are found in areas where the private values of land for alternative uses generally exceed the private value associated with habitat preservation. However, in this case, the threat from land loss was limited by US legislation. The Endangered Species Act, while protecting Northern Spotted Owl habitat, also protected some yew habitat. In areas that were logged, Pacific yew trees were considered to be of limited economic value before the discovery of taxol and the trees were frequently burned as waste. Even after taxol's potential benefits had been established, critics charged that logging companies clear-cut forest land, and continued their earlier practice of leaving yew trees as scrap to be burned. Congress subsequently passed the Pacific Yew Management Act to codify regulations requiring yew harvesting before commercial logging on federal land.

The second threat, the threat of over harvesting, emerged in the early stages of taxol development, in large part because this type of "pharmaceutical harvesting" had not been anticipated. Environmental groups complained that harvesters, hired by a Bristol subcontractor, were only taking bark that was easy to gather and leaving the rest to waste. This is a potential problem for the collection of any genetic material because incentives generally differ for harvesters and society as a whole.

Many holders of genetic resources may find themselves facing threats from over harvesting and/or habitat loss with prospecting successes. While the Pacific yew already experienced considerable protection, it still took an act of Congress to manage the harvest of one species in one region. Prospectors need to anticipate environmental consequences, as well as possible environmental regulations. This case also illustrates the limitations of dealing with biodiversity preservation in a reactive mode (on a species by species basis) rather than environmental planning on a habitat-wide basis. BDAs ideally would foster this habitat-wide conservation approach, or be supplemented by policies that do so.

Lesson 2. Modern technology may preempt the continued need for in situ genetic resources. Early in the development process, researchers realized the existing stock of yew trees could not sustainably meet the demand for taxol with existing technology. Bristol and NCI undertook a broad research program to develop taxol from sources other than Pacific yew bark.

Taxol was an exceptionally difficult molecule to synthesize. While complete synthesis proved to be commercially infeasible, semi-synthesis eliminated the need for continued Pacific yew bark harvesting.[22] Since the advent of biotechnology, most molecules can be semi-synthesized, if not completely synthesized. Therefore, a genetic resource developer may not need significant levels of in situ resources, which could limit increases to the marginal benefits to habitat preservation associated with a successful prospecting effort. This would decrease the incentives for the supplying country to conserve resources in situ after drug discovery (see also Macilwain, 1998, for a discussion about combinatorial chemistry).

Lesson 3. Genetic redundancy may not negatively affect the value of resources. It has been suggested that if similar drugs can be drawn from different species, or a species may be found over a wide geographic range, the species may have less value (Simpson et al., 1996).[23] Also, the concept of "medicinal redundancy" suggests that, because a disease or symptom may respond to different therapeutic mechanisms, the discovery of a successful drug eliminates the value of other treatments.[24]

Regarding the use of different species to produce the same drug, the case of taxol shows that species that are genetically similar can have different therapeutic properties. Taxol and its sister drug taxotere are very similar genetically and are both derived from yew species. However, the two are "clearly different drugs with different pharmacology, toxicity profiles and antitumor activity" (Scrip, 1995). For example, taxol is active in small cell lung cancer, but not melanoma, while taxotere is active in non-small cell lung cancer and melanoma (Scrip, 1995). Taxine drugs demonstrate that; while species with incremental genetic differences could be

[21] We also note that public sector R&D had removed considerable amounts of risk and uncertainty about taxol's efficacy and marketability, prior to the CRADA. Bunk (2000) notes that many BDAs would not exist without government funding.

[22] Several taxol sources other than Pacific yew bark have now been developed, and a semi-synthesized version of taxol has received FDA approval.

[23] Biologists use the term redundancy to describe a theoretical relationship between different species in an ecosystem. Walker (1992) and Lawton and Brown (1993) described the redundancy hypothesis, which states that the functional properties of species overlap such that the loss of any one species has a negligible impact on the ecosystem (Chapin et al., 1995). It has been suggested that this hypothesis, especially in its stricter forms, is unlikely to hold (Ehrlich, 1995). Myers (1996) suggested a "grey zone" with respect to ecosystem survival, in which certain species can be lost without affecting the resiliency of an ecosystem. However, it is unclear which (or how many) species can be lost without damaging the ecosystem.

[24] As described earlier, both Simpson et al. (1996) and Rausser and Small (2000) use one drug models.

considered redundant, in fact, a successful hit raises interest in closely related species.[25]

The case of taxol also suggests that the frequency with which a species occurs may not diminish its social value. If a species is readily available, there may be lower private returns to any holders of the resource. However, drug developers may still wish to pursue such a species and holders of endemic species, which are limited to a particular area or country, may be able to capture greater returns if all owners bargain collectively. The case of taxol also demonstrates that the use of a proprietary extraction process can generate private returns for those holding the rights to that process. (At the same time, it also suggests that returns to physical holders of resources may be small and short-lived.)

Finally, the fact that different drugs may treat the same condition does not necessarily negate the market value of any one drug. For example, taxol is usually used in concert with other drugs. Each attack the same cancer, but via different mechanisms. Ongoing conditions (e.g., asthma, heart disease, migraine headaches), which require continued treatment, often create demand for a regime of drugs.

Lesson 4. Local incentives or returns may differ from those of society. Concerns over the distribution of benefits are cited as a significant limitation to the ability of BDAs to sufficiently alter the incentives for land conversion (Barrett and Lybbert, 2000). In the case of taxol, most direct local benefits from genetic harvesting were both limited and temporary. The discovery of a valuable resource led quickly to mono-culture plantations and semi-synthetic production. Unless benefits are channeled, local resource holders benefits will accrue at the national (or global) level, rather than at the local level, where they are needed to influence land use decisions (Swanson, 1995). Thus, the case of taxol suggests that local benefits from a significant prospecting find can be small.

Lesson 5. While rewards for successful prospecting could be substantial, the time to drug discovery can be lengthy. By 1999, sales of taxol had reached $1.5 billion (Bristol-Myers Squibb Co., 2000). Even a small percentage of such a "blockbuster" drug's sales would be sufficient to alter the incentives for land use in the average developing country (provided the proceeds were distributed at the local level). At the same time, the taxol case demonstrates that drug development can be a long process. The bark source of taxol was first collected in 1962, but did not receive approval for marketing until 1992. In the US, development and approval of a new drug generally takes about 12 years (Special Panel, 1997). The process of adapting natural substances for human use can take even longer. Thus, assuming a promising natural product is found, the time between the initial collection and a financial return may be unacceptable to many BDA participants.

Lesson 6. Biodiversity development agreements should be structured carefully. The taxol development agreement was carefully constructed to ensure that economic returns would be sufficient to attract a major pharmaceutical company. Lacking formal intellectual property protection, exclusive access may be necessary to satisfy the needs of private companies. Second, NCI had an opportunity for recourse if it appeared that Bristol was not developing the drug rapidly enough. Finally, protection of the yew and surrounding forest was safeguarded by provisions requiring Bristol to conduct environmental impact studies and find a substitute for yew bark.

A source country will want to construct BDAs so they provide all these characteristics: commercial appeal, accountability and resource conservation. Moreover, source countries will also want BDAs that offer economic and social benefits. However, such BDAs may be difficult to negotiate unless the source country has promising and unique resources.

Applying some of the lessons from taxol's development can help us evaluate Costa Rica's success with BDAs. The Costa Rican experience with BDAs illuminates some of the benefits of BDAs, as well as some of the limitations, particularly for habitat-wide conservation. It also points to some important issues in the structuring of BDAs.

Costa Rica and biodiversity development agreements

Costa Rica is thought to be one of the world's richest biodiversity holders (Rouhi, 1997). Costa Rica has designated more than 25% of its total area as protected areas. These wildlands alone are believed to contain about 4% of the world's biodiversity. Costa Rica has begun a concerted national program to conserve and market their biodiversity. To this end, INBio was established in 1989 to generate intellectual and economic income from biodiversity, to help preserve Costa Rica's biodiversity. INBio operates in partnership with the government's ministry for natural resources to inventory biodiversity, prospect for valuable resources, manage information and disseminate results (INBio, 2000).

The Merck–INBio agreement

One of the first BDAs was between the pharmaceutical company Merck & Company and INBio in Costa Rica (Simpson and Sedjo, 1992; Blum, 1993; Reid et al., 1993; Roberts, 1992). The agreement originally was a 2-year collection contract, in which INBio received a $1 million payment plus more than $100,000 in equipment.

[25] Polasky and Solow (1995) cite the example of taxol to call into questions economic assumptions about perfect substitution and independence of species.

INBio scientists have received technical training locally and at Merck facilities. INBio is also to receive an undisclosed percentage of royalty payments for any discoveries Merck makes, to be shared with Costa Rica's Ministry of Natural Resources. Merck retains first rights to patent discoveries, however (Blum, 1993). In February of 1997, this agreement was renewed for the second time. Merck was expected to provide an additional $1 million in research funds during 1997 and 1998 (Rouhi, 1997). In addition, INBio has been paid for sample collection and processing.

If the Merck–INBio agreement were Costa Rica's only BDA, it is unlikely that the economic returns would be sufficient to finance Costa Rica's national biodiversity conservation goals. To date, Merck has paid several million dollars (plus overhead) as well as provided employment and training opportunities. In view of the opportunity costs of this land given by Barbier and Aylward (1996), the resources received from Merck thus far seem woefully inadequate. In fact, some critics have charged that Costa Rica and INBio gave Merck too much access to its resources at too cheap a price (Blum, 1993; Meyer, 1996; see also Southgate, 1998). Of course, if the Merck–INBio agreement were to produce a taxol-caliber drug, then the resulting royalties would provide significant resources for conservation work. Such an event would probably not occur for some time, given the time lags typical in drug development. However, INBio has entered additional BDAs, described below.

Other agreements

Besides the Merck BDA, INBio was part of an International Cooperative Biodiversity Group (ICBG). This program was begun by the US National Institute of Health (NIH), the US National Science Foundation, and the US Agency for International Development. Costa Rica (through INBio and the Guanacaste Conservation Area) cooperated with Cornell University and Bristol-Myers to collect and screen insects as a source of drugs (Rouhi, 1997). The project used a targeted screening approach to focus on insects that use chemicals in plant/predator interactions (Rosenthal, 1996). The project's leader pointed out that drug discovery, economic development, and conservation were the stated goals of Costa Rica's ICBG. However, the ICBG also sought ecological information that is useful for conservation, but that does not necessarily lead to drug discoveries (Rouhi, 1997). One goal of the ICBG program has been to balance prospects for long-term and short-term economic returns. NIH's representative, Josh Rosenthal noted that source countries should "... maximize the research process itself to provide alternatives to unsustainable use of genetic resources" (Rouhi, 1997, p 29). Costa Rica's ICBG was described as "front-loaded with infrastructure building" (Rouhi, 1997, p 29). Because this BDA was initiated by the public sector, it was believed to yield better immediate returns to the source country, as well as the ongoing possibility of future royalty payments.

Costa Rica has entered other BDAs that are not focused on drug discovery. One innovative agreement is between INBio, Kew Gardens (UK) and another pharmaceutical company. The British Technology Group holds the patent on a nematicide produced by a Costa Rican tree. The compound has action against nematodes that attack banana and coffee plants (among other crops), while being benign for mammals (Tenenbaum, 1995). INBio has been licensed to produce and sell the chemical in Costa Rica. Costa Rica will receive royalties and production-related jobs and will also benefit from an environmentally sound pesticide that is expected to improve banana production (Tenenbaum, 1995).

Not all of Costa Rica's BDAs involve prospecting for chemicals. As noted, data efforts have been an integral part of INBio mission. Intergraph Corporation, a US information company, and INBio have been collaborating on a Biodiversity Information Management System. Intergraph has supplied hardware and software to INBio, in exchange for the opportunity to sell computer resources to biodiversity users (Meyer, 1996). INBio's database, containing biogeographic and taxonomic about both species and ecosystems (Sittenfeld and Artuso, 1995), has been praised because it offers Costa Rica the opportunity to benefit from its biodiversity outside the chemical prospecting arena (Nature Biotechnology, 1998). This data effort has garnered additional support from the World Bank in 1997, when the World Bank's Global Environmental Facility signed an agreement with INBio to further develop biodiversity data resources in Costa Rica (World Bank, 1997). The seven-year project, which began in 1998, involves nearly $8 million in resources. Funded activities also include training, equipment, and institutional strengthening. Additional inventories have been financed by the Missouri Botanical Garden and the Dutch Government. The Dutch effort (which is expected to provide $12 million to INBio) also includes provisions for infrastructure building, training, and joint ventures with the private sector (World Bank, 1997).

Evaluation of Costa Rica's BDAs

Costa Rica's BDAs should be evaluated for the ability to accomplish several related objectives. First, will the agreements bring in economic and social returns and will returns be sufficient to finance continued in situ conservation? Second, will returns generated by the BDAs be transmitted to the local level where conservation needs to take place?

Regarding the expected returns to BDAs, Costa Rica's pharmaceutical prospecting presents a long-term investment with an uncertain potential of success. In the short run, the money from Merck available for in situ conservation will not finance the setting aside of a significant area of land.[26] And while the BDA was structured so that Costa Rica will receive a percentage from the sale of any commercialized products, royalty payments from drug discoveries may take many years to arrive. However, if pharmaceutical success such as taxol were achieved, Costa Rica stands to receive impressive royalties that could fund its conservation activities in the future. While the percentage of total sales designated as royalties is rumored to be small, even 2–3% of a billion dollars worth of drug sales would be a significant sum of money, especially when compared with Costa Rica's annual budget (Rouhi, 1997). Rausser and Small (2000) liken prospecting to a lottery: there is a low probability of success, but payoffs for a success are high.[27]

There are additional benefits for Costa Rica, which do not depend on a successful pharmaceutical discovery. The first benefits of education, training, capacity building and job creation resulting from the early BDAs[28] have allowed Costa Rica to expand its value-added activities, thus increasing its opportunities (Sittenfeld and Lovejoy, 1998). Costa Rica's subsequent projects with public sector institutions have generated additional funds for INBio, funds that appear to be greater than those of the private BDAs.[29] Moreover, new natural products for agriculture and industry are beginning to emerge, offering the possibility of more immediate monetary returns to BDAs. Of course, Costa Rica has set aside substantial areas of land, areas that it intends to conserve regardless of prospecting outcomes.[30] And Costa Rica has used most of the resources brought in to date to finance conservation programs that include land preservation.[31] Thus, in Fig. 1, the MB_{con} curve also can be thought to shift, in this case to the left, because the benefits to land conversion are tempered by legal repercussions for destroying habitat.

The prospects for creating conservation incentives for land users are not completely clear. The Merck BDA emphasized collection, cataloguing and ex situ storage of genetic materials. Ex situ preservation is important, but, again, it is unclear how such biodiversity development has translated into local incentives for in situ preservation. The ability of firms to synthesize compounds also reduces their incentives to fund in situ preservation once genetic materials are collected.[32]

On the positive side, training and employment are benefits that have been transparently transmitted to the local level. Moreover, setting aside a significant area of land has facilitated the use of other means of protection for its biodiversity. Under the UN Framework Convention on Climate Change, Costa Rica has established an office for joint implementation (OCIC). The OCIC has helped develop a number of private and joint public–private projects for land conservation, forest regeneration, and tree plantation initiatives (Chacon et al., 1998). The efforts include means to facilitate the preservation of privately-held lands designated for protection by offering carbon mitigation though Certifiable Tradable Offsets (buyers include the US and Norway). Costa Rica has been a pioneer in "debt for nature swaps." Costa Rica has also received funds from the US government for holding land as migratory bird habitat (Tenenbaum, 1995). The combination of these instruments has raised the profile of Costa Rica and aided its enthusiastic pursuit of ecotourism ventures (Terborgh, 1999).[33] Ecotourism may provide more immediate returns to biodiversity preservation at the local level, and increase the benefits associated with preservation. Wiebe and Meinzen-Dick (1998) point out that holding a "partial interest" in land-based resources can foster environmentally desirable behavior. The authors offer the example of the Zimbabwe Campfire program, in which local communities can capture the income that local wildlife generates from hunting and tourism. Legally, the biodiversity found on preserved land is held publicly by the nation. However, if Costa Ricans perceive that they have a partial interest in local land and expect to receive benefits from this preserved land (through any of the instruments described above), this may motivate land-conserving behavior. Whether Costa Rica has reached the volume of benefits needed to change local incentives for wildland conversion is uncertain. Thus, referring back to Fig. 1, we would expect some outward movement in the marginal benefits curve (MB_L), but it

[26] Ninety percent of Merck's initial payment to INBio was allocated to prospecting activities, while only 10% was allocated to the government's National Parks Fund (Sittenfeld and Lovejoy, 1998).

[27] Probabilities of a successful hit range significantly. For example, Farnsworth and Soejarto use a success rate of one per every 125 species. Simpson et al. (1996) use one in 25,000; Mendelsohn and Balick use one in 1,000,000. As noted before, Cragg et al. (1998) cite a success rate of one in 4000 based on the National Cancer Institute's experience.

[28] The initial training of parataxonomists was also supported by the US Agency for International Development, the Swedish International Development Authority, and the Pew Charitable Trusts.

[29] The justifications for these public-sector BDAs/inventory projects cite the training and institutional knowledge gained from the early BDAs (World Bank, 1997).

[30] Of the area of land formally protected by Costa Rica, 10% is privately owned, and 16% is held by non-governmental organizations (Chomitz et al., 1998).

[31] While there still may be local pressure to convert protected land, as well as significant enforcement costs to assure resource protection, without any set-asides, land preservation would be far less likely.

[32] Though we note that Eisner (1989–90) has argued that synthetic replication of genetic resources removes harvesting pressure on those resources.

[33] And some of the proceeds from BDAs have been used to establish ecotourism guidelines (Sittenfeld and Lovejoy, 1998).

may be very slight. Making a causal link between land use trends and BDAs is limited by an insufficient time since the agreements were enacted and other confounding factors (including changes in agricultural policy and the relatively large role played by other conservation measures).

One additional limitation to Costa Rica's BDAs as a conservation tool is that the BDAs fund conservation activities on public lands but not on private lands where much deforestation is occurring. Silk (1993) notes that many of Costa Rica's endangered species live outside nationally designated protected areas. Other conservation tools, such as incentive payments or easements, may be more likely to motivate conservation on private land than the BDA approach used by Costa Rica.[34]

To summarize, the Merck/INBio BDA, alone, provides modest incentives for biodiversity preservation, at this point in time. Costa Rica's additional BDAs and other agreements have further capitalized on Costa Rica's resources and reputation as a provider of biodiversity. And some of these agreements have the potential for more immediate payoffs than the Merck BDA. Thus, BDAs may provide greater marginal benefits and financial resources at the national level for preservation in the near future. Still, however, the role of BDAs in preservation is tempered by the economics of land use and the country's socioeconomic position, which are powerful influences on land use choices.

Thus, questions remain about whether these BDAs can provide sufficient incentives, compared with the incentives that exist for land conversion. A truly comprehensive preservation strategy must directly address all factors affecting the opportunity costs of preservation, and is unlikely to be achieved with BDAs alone. Fortunately, Costa Rica has been using a variety of instruments to promote conservation.

When considering the applicability of the INBio experience to other developing nations, it should be noted that there are some unique aspects to Costa Rica. Biologically speaking, about 20% of Costa Rica's biodiversity is endemic and cannot be found anywhere else in the world (Rojas and Jaffe, 1994). Given INBio's management of these resources, this creates a monopoly-like situation (Meyer, 1996). Costa Rica is also distinctive in terms of socioeconomic status. Compared with many developing countries, Costa Rica has substantially higher levels of education, literacy, health and a stable government (Meyer, 1996; Blum, 1993; Silk, 1993). These factors have made Costa Rica an attractive partner to commercial resource developers, and other countries without these biological and sociopolitical advantages may not have as many interested collaborators as Costa Rica (nor have its bargaining power).

[34] Silk (1993) notes that the Costa Rican property law allows for use limitation on private lands, and that some legislation has focused on the application of use limitations for environmental reasons.

Conclusions

While this paper focuses in BDAs, it should be noted that most biodiversity preservation depends on a variety of incentives for different land use. Unfortunately, sufficient attention is not always paid to the potential of BDAs compared with the dynamics of opportunity. While the focus has been on BDAs as a way to correct market failures and increase the benefits of biodiversity conservation, in general, most of the benefits of biodiversity are non-market goods. Thus, correcting local market failures, vis-a-vis marketed genetic resources, will only produce a limited set of incentives to reduce wildland conversion. The effects of such factors as agricultural markets, population pressure, poverty, and government land use policies have a profound effect on the returns to competing uses of forest land. From this perspective, increased demand for agricultural land leads to biodiversity loss independent of these direct-use market failures. Moreover, there is substantial evidence that the opportunity costs of preservation are rising rapidly in many biologically diverse regions. Where this is the case, market mechanisms (such as BDAs or ecotourism) that allow countries to capture greater benefits from preservation may have less impact. Identifying and addressing the collection of resource constraints, socioeconomic factors and government failures that cause the opportunity costs of preservation to rise to a socially undesirable rate is necessary.

Nonetheless, BDAs can be an important component of a portfolio of conservation strategies. As the development of taxol demonstrated, the returns to pharmaceutical prospecting can be substantial. However, successful prospecting efforts are not guaranteed to protect in situ resources. Harvesting can damage in situ resources, and synthesis of valuable resources can remove the incentive to continue in situ protection. Other forms of biodiversity protection may be advisable. Provisions to use returns from successful finds to finance conservation (such as Costa Rica's) may be needed.

Source countries also need to structure BDAs carefully, to achieve all their objectives. The Costa Rican experience illustrates that BDAs can be used to accomplish multiple objectives. Careful negotiation of agreements has allowed Costa Rica also to expand the types of returns arising through BDAs. By diversifying into agricultural and information products, Costa Rica is enhancing its opportunities for both long and short-term returns. BDAs have expanded Costa Rica's human capital and employment opportunities, and strengthened its infrastructure. Finally, increasing knowledge and institutional capacity is informing conservation policy in Costa Rica, which may improve its efficacy.

Thus, while BDAs alone may not be sufficient to preserve resources, they hold promise as one facet of a comprehensive biodiversity conservation effort.

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